Variable-Rate Nitrogen Fertilizer Application in Corn Using In-field Sensing of Leaves or Canopy

September 15, 2006

Purpose.
This technical note provides guidance to Missouri farmers for using sensing devices to measure the relative nitrogen (N) health of corn plants and making variable-rate N fertilizer applications. Nitrogen fertilization using the technologies and procedures described here requires familiarity with sensor data collection and variable-rate controllers. Other issues to consider before deciding to use these technologies and procedures are listed Tables 1 and 4. It is also recommended you consult with a USDA-NRCS regional or state nutrient management specialist.

Situation.
Because soil types within individual fields can be highly variable, the amount of N provided by those different soil types to support corn production can also be highly variable. As a result, when a uniform rate of N fertilizer is applied over the entire field, substantial areas can be over-fertilized while others areas are under-fertilized. Climate factors such as precipitation (both the amount and seasonal distribution) and temperature also cause soil N to behave differently each year, making it very difficult to predict how much will be available for the crop and how much supplemental fertilizer N should be added. Ideally, the amount of N fertilizer added during a given growing season should be both climate-sensitive and site-specific. The fertilizer rate chosen for each area in the field would optimize profitability for the farmer (called the economical optimal N rate) and minimize over-application. If too little N is added, profitability is lost. Applying more N than what is needed results in the unused N being left in the soil after harvest, usually as nitrate-N. Unused nitrate-N can move to groundwater, to surface water bodies, or denitrify from the soil into atmospheric greenhouse gases, all pathways that cause environmental concern.

In the U. S. Corn Belt, fall to late-spring is the time period when nitrogen is most vulnerable to loss, when plant growth is minimal. However, uncertainly exists regarding how much N fertilizer should be applied to meet crop needs (without over- or under-fertilizing) for other time periods and management situations (see Table 1). Applying N at side-dress so that it is synchronized with crop N uptake helps reduce potential N loss, but applying the correct amount of N is equally if not more beneficial in reducing losses. Missouri research has shown that when N fertilizer rates exceed the amount needed, there are higher amounts of post-harvest nitrate-N that is vulnerable to loss into the environment.

Nitrogen loss off grain-production fields in cold and temperate regions occurs mainly from fall to late spring, when plant growth is minimal. As such, N that is left in the soil after the fall harvest or when N fertilizer is applied in the fall or early spring (a common practice in the U.S. Corn Belt) is highly vulnerable to movement into groundwater, lakes, and streams. For many other situations uncertainty exists about how much N fertilizer should be applied to meet crop needs without under- or over-application (See Table 1). Applying N at side-dress so that it is synchronized with crop N uptake helps reduce potential N loss, but applying the correct amount of N is equally if not more beneficial in reducing losses. Research has shown that when N fertilizer rates exceed what is needed, there are higher levels of post-harvest soil nitrate and a high risk of N loss to the environment.

Background
Producers would like to apply the right amount of N needed by the crop, so that profitability is maximized and negative environmental effects are minimized. This is difficult because of within-field variability and the other situations creating uncertainty, like those identified in Table 1.

Table 1. The best opportunity (economic and environmental) for using plant sensors to make variable-rate N applications is where uncertainty is high about the right amount of N to apply. Potential scenarios include:

- Fields with extreme variability in soil type (e.g., flood-plain soils)
- Fields experiencing a wet spring or early summer (loss of applied N) and where additional N fertilizer is needed
- Fields that have received recent manure applications, due to uncertainty in how much N is available from the manure
- Fields receiving uneven N fertilization because of application equipment failure or because of mis-calibrated equipment (for either fertilizer or manure application)
- Fields coming out of pasture, hay, or CRP management
- Fields of corn-after-corn, particularly when the field has previously been cropped in a different rotation
- Fields following a droughty growing season (i.e. non-uniform carry-over of soil N after the drought year)

Why Crop Canopy or Leaves*?* Because N is a primary constituent of plant chlorophyll pigments and this is where photosynthesis takes place, leaf or crop canopy color can be used to evaluate crop N health. An obvious advantage of using plant color for within-season N input decisions is there is little time delay between measurement and interpretation, such as occurs in soil sampling and analysis. Further, because each plant expresses crop N status for its given location, plant sensing provides the best opportunity for quantifying detailed spatial variability of crop N need. A primary disadvantage of using the plant for assessing N need is that it narrows the window of time when N applications can take place, typically knee- to chest-high corn.

While sensors can be used to examine individual plants or leaves, practical concerns usually dictate assessing reflectance characteristics of the crop canopy for large crop production fields. How does it work? By definition, crop reflectance is the ratio of the amount of light leaving the canopy to the amount of incoming light. In the chloroplasts, plants transform light energy to chemical energy (photophosphorylation) most efficiently by absorbing red (630-680 nm) and blue (450-520 nm) wavelength light. Green light (520-600 nm) is absorbed much less by plants, producing higher reflectance in this wavelength range. Hence, sensing reflectance at visible wavelengths can provide a relative measure of leaf chlorophyll content.

Additionally, inclusion of non-visible reflectance related to the amount of plant biomass is helpful for assessing crop N health. Plants absorb much less near infrared light (700-1400 nm) than does soil. This difference in absorption between soil and plants provides a contrast that, along with visible reflectance, has been the basis for numerous biomass or vegetative indices. An example is the *normalized difference vegetative index* or NDVI. Calculations combining visible light reflectance (a measure of the plant's photosynthetic health) with near infrared reflectance (a measure of the plant's structural capacity to assimilate carbon) have been successfully used in evaluating crop N health and making N fertilizer additions.

Sensors for Assessing N Health of the Plant. There are two different sensor types that can be used for measuring the N health of corn and making N fertilizer recommendations: 1) a hand-held chlorophyll sensor, and 2) crop canopy reflectance sensor.

<u>*1. Measuring Leaf Chlorophyll With a Hand-Held Sensor.*</u> A commercial hand-held chlorophyll meter (Minolta SPAD-502)[1] measures leaf transmittance centered at red (650) and near infrared (940 nm) wavelengths and has been shown to be sensitive to N stress in corn and other crops. To operate, the meter is clamped onto a single leaf to prevent interference from external light. The meter senses transmittance through a very small area of leaf with each reading. While individual plant readings can

be rapidly obtained, acquiring a representative value for large cornfields is time consuming. It is especially difficult to obtain representative measurements for fields with significant spatial variability plant N health. For this reason, chlorophyll meter sensing to assess production-scale crop N health and variable-rate N may not be practical for many producers.

2. Measuring Canopy Reflectance On-the-Go With Active Canopy Sensors. Active reflectance sensors have been developed that emit their own source of modulated light onto the crop canopy at fixed wavelengths using light emitting diodes (LEDs), and then detect canopy reflectance with photodiodes. Sensor types known to be available for sale as of 9/2006 are the *Holland Scientific Crop Circle ACS-210 Plant Canopy Sensor* and the *NTech Industries Inc. GreenSeeker* sensor. The advantage of these types of sensors over passive-light reflectance sensors is that they remove the varying effects of sunlight (e.g., sun angle and cloudiness) by having their own artificial light source. These sensors measure both visible and near infrared wavelength reflectance from which vegetative indices can be calculated. Operationally, these sensors can be mounted on N fertilizer applicators equipped with computer processing and variable rate controllers so that sensing and fertilization is done in one pass.

A Reference is Required. When using either of these sensor types, determining the rate of side-dress N requires sensor measurements from a *sufficient-N reference* area, corn that has been well-fertilized since planting. In principle, the greater the difference in sensor measurements between *sufficient-N reference* corn and un-fertilized or deficiently-fertilized corn, the more N fertilizer is needed. Without this reference to determine a relative difference, there is no basis for making N rate recommendations. The *sufficient-N reference* corn is fertilized before or shortly after planting so that N is not a limiting factor up to the time of sensor measurements and side-dress N application. Hybrids vary subtly in color, so each hybrid needs its own *sufficient-N reference*.

Procedures.

<u>Hand-Held Chlorophyll Meter.</u>

1. **Reference.** Establish a *sufficient-N reference* area just before or just after planting. Avoid areas that historically have had other management problems (e.g., heavy weed infestation, head-lands with soil compaction). For the chlorophyll meter, the area needs to be a minimum of 300 ft^2 (e.g. 10 x 30 ft or 15 x 20 ft). Since such a small area is being fertilized, one may find it more practical to fertilize by hand than by standard field fertilizer equipment. For this reference area, target a rate of 200 lbs/acre. For an area of 300 ft^2, 4 lbs of dry ammonium nitrate or 3 lbs of dry urea is sufficient and equivalent to a rate of about 200 lbs of N/acre. This can be uniformly spread by hand or by using a standard garden/yard broadcast or drop spreader. Mark the corners of the reference area with flags or stakes for easy identification later.
2. **Management Zones.** To perform variable-rate N management, the field needs to be divided into unique management zones. These zones are to be no larger than 10 acres. The zones should be based upon some understanding of the likely variability in corn N health found in the field. Consider using information like an NRCS soils map, a soil electrical conductivity map, or on an aerial photograph just before the chlorophyll meter readings. This delineation of the field into zones defines the sub-field areas used for variable-rate N application. Ideally, establish a *sufficient-N reference* area for each zone.
3. **Meter Check.** Read and follow chlorophyll meter instruction manual for operation, care, and cleaning. Check to ensure the meter is functioning properly by testing the meter with the calibration disc that comes with each meter.
4. **Meter Readings.** Collect chlorophyll meter readings within three days of when side-dress N fertilization is planned. To collect measurements, simply place a corn leaf between the sensor clamps and hold the clamps down so that sunlight is shielded from the sensing area. The meter responds with a distinct audible signal when a reading has been taken incorrectly. Always place the top of the meter on the top side of the leaf and approximately halfway down the leaf from the tip to the base. Before tasseling, obtain readings from the uppermost leaf that's fully collared (leaf collar fully visible around the stalk). After tasseling, obtain readings from the ear leaf.
5. **Locations.** Obtain readings from 20 to 30 different corn plants from each management zone for which a N-rate recommendation is being determined (called *target* corn). Plants within each zone should be selected randomly and should be representative of the whole zone. The meter calculates an average up to 30 sensor measurements by pressing the "average" button. Record values. Also, obtain and record readings from 20 to 30 different plants from the *sufficient-N reference* corn.
6. **Calculations**. Calculate the Relative Chlorophyll Meter value (RCM) as follows:

   RCM = meter value of *target* / meter value of *sufficient-N reference*

   Now calculate the amount of N to apply (not to exceed 220 lbs of N/acre):

   For V6-V9 corn (1ft to 3ft): N fertilizer (lbs N/acre) = 810-(785 x RCM)
   For V10-R1 corn (4 ft to tasseling): N fertilizer (lbs N/acre) = 563-(554 x RCM)

Calculated N rate recommendations from these two equations are shown in Table 2.

Table 2. Nitrogen fertilizer recommendations based on chlorophyll meter measurements.

	Relative Chlorophyll Meter value (RCM)																			
	1.00	0.98	0.96	0.94	0.92	0.90	0.88	0.86	0.84	0.82	0.80	0.78	0.76	0.74	0.72	0.70	0.68	0.66	0.64	0.62
GROWTH STAGE	N fertilizer (lbs N/acre)																			
V6-V9 corn (1 to 3 ft)	25	41	56	72	88	104	119	135	151	166	182	198	213	220	220	220	220	220	220	220
V10-R1 corn (4 ft to tasseling)	9	20	31	42	53	64	75	87	98	109	120	131	142	153	164	175	186	197	208	220

7. **Fertilize.** Apply fertilizer for each management zone at the calculated N rate.

<u>Active Canopy Sensors.</u>

1. **Reference.** Establish a *sufficient-N reference* area just before or just after planting. Target a rate of 200 lbs/acre. For fields with highly-variable soils, multiple areas or N reference strips positioned to capture this soil variability is recommended. Avoid areas that historically have had other management problems (e.g., heavy weed infestation, head-lands with soil compaction). The reference area needs to be wide enough to include all sensors when mounted on the fertilizer application equipment (typically 30 ft wide is sufficient), and a minimum length of 50 ft for a single area. When only a single reference area is used, one may find it more practical to fertilize by hand than by standard fertilizer equipment. For an area of 1500 ft^2 (30 x 50 ft), 20 lbs of dry ammonium nitrate or 15 lbs of dry urea is sufficient and approximately equivalent to a rate of about 200 lbs of N/acre. This can be uniformly spread by hand or by using a standard garden/yard broadcast or drop spreader. Mark the corners of the reference area with flags or stakes for easy identification later.
2. **Sensor Check.** Follow manufacturer's instructions for installation and operation.
3. **Hand-Held Canopy Sensor Readings.** These canopy sensors can be set up to work in a hand-held mode (see manufacturer's information) and measurements electronically recorded while walking next to a corn row. If used in this way, follow instructions for *Management Zones* in the previous section on the *Hand-held Chlorophyll Meter*. For areas to be side-dress fertilized (e.g., target corn), measure and average a minimum of ten 25-ft row segments to represent the management zone and calculate an N rate. (Operation of these sensors in hand-held mode is not ideal for collecting site-specific information for variable-rate N applications in large production fields.)
4. **On-the-Go Sensing and Fertilization.** The preferred way to use these sensors is mounted on a tractor or high-clearance vehicle that can straddle over the top of the corn crop. This same vehicle is the N fertilizer applicator, equipped with a computer that can process the sensor information and a variable-rate N controller--- a one-pass sense and variable-rate N application system. The width of the variable-rate application should be considered when deciding how many sensors should be installed. A minimum of 2 sensors on 2 different rows are to be used for representing the applicator swath width. More may be warranted for wide applicators. The system should be tested for appropriate delay settings (i.e., time of sensing, calculation, fertilizer application response) and calibrated for the targeted application rates before going to the field for application. Ensure that the equipment is capable of delivering the range of N rates likely required and at the speed of field operations.
5. **Sensor Height**. The sensors need to be mounted and operated so that they are level and directly aligned over corn rows. Distance from the sensors to the crop canopy should be from 24 to 36 inches.
6. **Sensor Measurements.** At the time of side-dress N fertilization, sensor readings are first taken from the *sufficient-N reference* corn. Reference values are stored in the computer for on-the-go calculations. The applicator then drives over the rest of the field sensing, calculating, and applying N variably, all in one pass.

7. **Calculations and Fertilization**. The vegetative index used for N fertilizer recommendations for Missouri is the ratio of the visible reflectance measurement to the near infrared reflectance measurement:

   ratio = visible/near infrared

   Ratio measurements from both the *sufficient-N reference* and from on-the-go *target* areas are combined for calculating N fertilizer recommendations as shown in Table 3.

Table 3. Equations for calculating N rates (lbs N/acre) from active canopy sensors.

	Corn Growth Stage *, **	
Sensor Type	**V6-V7 (1 to 1.5-ft tall corn)**	**V8-V10 (2 to 4-ft tall corn)**
Crop Circle	$(330 \times ratio_{target} / ratio_{reference}) - 270$	$(250 \times ratio_{target} / ratio_{reference}) - 200$
GreenSeeker	$(220 \times ratio_{target} / ratio_{reference}) - 170$	$(170 \times ratio_{target} / ratio_{reference}) - 120$

** The value of the* $ratio_{reference}$ *should not exceed 0.28. Set this as a ceiling.*
*** With all equations, maximum N rate should not exceed 220 lbs N/acre.*

Summary.
This technical note provides guidance for Missouri farmers for using sensing devices for making variable-rate N fertilizer applications. Some fields will be more suitable than others for using these technologies and procedures (Table 1). Additionally, Table 4 lists other points and risks that should be considered with this type of N management.

Table 4. Points and risks to consider.

1. Procedures described here require a familiarity with sensor data collection and variable-rate controllers.
2. Use application and control systems that will match the desired range of variable-rate N application.
3. Do not use these sensors and procedures before the corn is 1 ft tall.
4. Many soils will need some N fertilizer for early growth. This can be added with P fertilization (MAP or DAP), starter fertilizer, manure additions, or other pre-plant fertilizer operations. For low to medium productive soils, 30 to 40 lbs is usually sufficient. For high productive soils (5-yr corn yield average > than 160 bu/acre), early-season N is crucial for maintaining high yield. High productive fields should be fertilized with 40 to 60 lbs N/acre before or at planting. More than 60 lbs N/acre early, and one runs the risk of not being able to accurately detect additional need using the sensors.
5. Unless high-clearance equipment is used, only a narrow window of time (~2 to 3 wks) is typically available for doing N applications in knee- to waist-high corn. The potential for extended periods of inclement weather need to be considered when determining how many acres can be covered by a fertilizer applicator.
6. Surface-applied side-dress N will not generally be available for plant uptake until precipitation moves the N into the root zone, a risk that should be considered. A volatilization inhibitor should be considered when side-dressing urea-based N fertilizer on the surface.

[1] Mention of trade names or commercial products in this Note is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.